4.3 Determining the magnifications of a microscope and a telescope

Components required: small illumination lamp, white light source, plate holder, 1/10 mm reticle, millimetre ruler, biprism holder, lens holder(2), 45° glass holder, microscope eyepiece, stand ruler, adapter piece, and lenses f'=45 and 190 mm.

4.3.1 Magnification of a microscope

As shown in Figure 4.3-1**,** the optical system of a microscope employs an objective with a short focal length and a magnifying eyepiece. The magnification is achieved in two stages as shown in Figure 4.3-1. The microscope objective forms an enlarged image of the object in a position that is suitable for viewing through the eyepiece; the magnification through the objective is given by

$$y_2/y_1 = \Delta / f_o' \qquad (4.3\text{-}1)$$

Generally speaking, the focal length of the eyepiece f_e' is much less than the distance of the image from the eyepiece *D*, (for normal sight, D is approximate 250 mm), so

$$y_3/y_2 \approx D/f_e' \qquad (4.3\text{-}2)$$

Then we get the total magnification:

$$M = \frac{y_3}{y_1} = \frac{y_3}{y_2}\frac{y_2}{y_1} = \frac{D\Delta}{f_o' f_e'} \qquad (4.3\text{-}3)$$

Where Δ is the distance between the focus of objective and the focus of eyepiece, f_o' is the focal length of objective and f_e' is that of eyepiece.

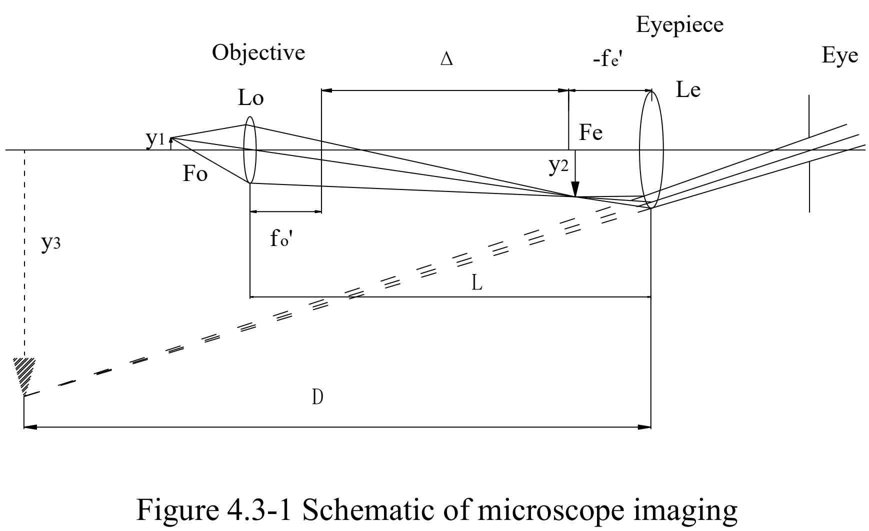

Figure 4.3-1 Schematic of microscope imaging

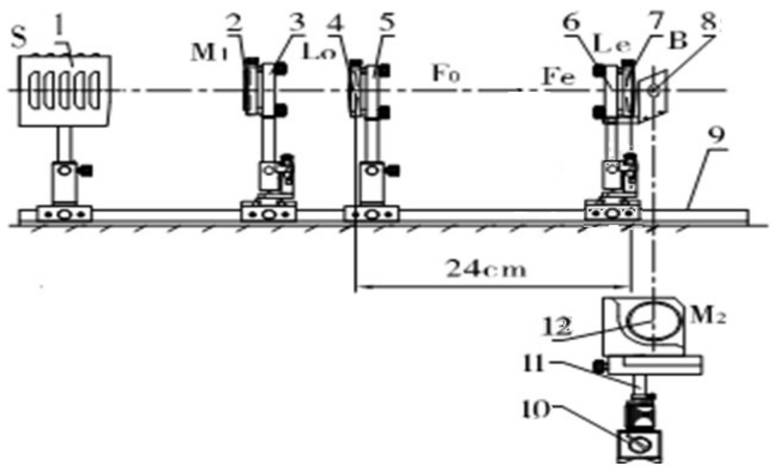

Figure 4.3-2 Schematic of experiment setup

1: Bromine Tungsten Lamp *S* (LLC-3)
2: Reticule M_1 (1/10 mm)
3: Biprism Holder (SZ-41)
4: Objective Lens Lo ($f_o^{'}$=34 mm)
5: Two-axis Tilt Holder (SZ-07)
6: Eyepiece Lens *Le* ($f_e^{'}$=45 mm)
7: Lens Holder (SZ-08)
8: 45° Glass Holder (SZ-45)
9: Optical Rail (LEPO-54)
10: Magnetic Base (SZ-04)
11: Lens Holder (SZ-08)
12: Millimetre Ruler M_2 (l = 30 mm)
Other: Small illuminating lamp (LLC-6) mounted on plate holder SZ-12, adapter piece SZ-09A.

Experiment Procedures:

1) Refer to Figures 4.3-2, align all components in same height along the rail;
2) Fix interval between *L*o and *L*e as D = 240 mm;
3) Move reticle plate M_1 back and forth, till a clear M_1 virtual image is observed behind *Le*;
4) Mount the beam splitter (*B*) behind the lens *Le* on the post of lens holder 8 (the glass plate is at 45° angle with respect to the optical axis);
5) Place the millimetre ruler M_2 beside the *B* (vertical to main optical axis along the rail) and approximate 250 mm distance from *B (in diagram)*; it is illuminated by the small illuminating lamp from its back; (i.e. mount the millimetre ruler M_2 on a lens holder; then install the millimetre ruler and the small illuminating lamp at the two ends of the adapter piece SZ-09A.)
6) View behind *B* by one eye, finely rotate B's angle to overlap the microscope virtual image from M_1 and the M_2 image from the glass reflection; adjust the brightness of the LLC-3 lamp to achieve close brightness of the two images.
7) Finely adjust M_1 to eliminate viewing difference between the two images;
8) Count the scale amount *a* in M_1 image included in the range of 30 mm of image M_2;

9) Calculate the measured magnification of the assembled microscope and its theoretical magnification:

Measured Magnification: $M = \dfrac{30 \times 10}{a}$

Theoretical Magnification: $M' = \dfrac{250 \times \Delta}{f_o' f_e'}$, where, $\Delta = D - (f_o' + f_e')$.

4.3.2 Magnification of a telescope

As seen in Figure 4.3-3, the magnifying power of a telescope used for observing an object at infinity is defined as the angular magnification at the pupil because the angle are very small:

$$M = \frac{\tan \omega'}{\tan \omega} = \frac{\omega'}{\omega} = \frac{f_o'}{f_e'} \tag{4.3-4}$$

where f_o‘ and f_e‘ are the focal lengths of the objective and eyepiece lenses, respectively, and w’ and w are the object and image angles at the eyepiece and objective lenses, respectively.

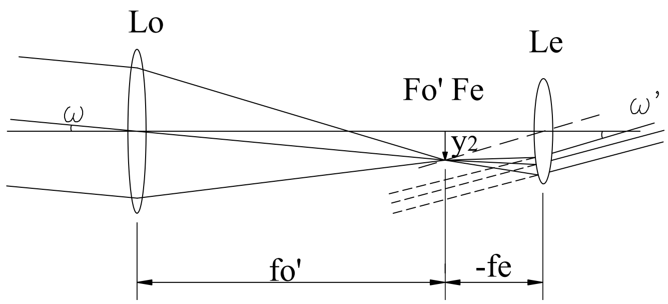

Figure 4.3-3 Schematic of telescope imaging at infinity

As shown in Figure 4.3-4, when observing an object at quasi-infinity, the power of magnification is:

$$M = \frac{\tan \omega'}{\tan \omega} = \frac{y_2 / s_2}{y_1 / (s_1 + s_1' + s_2)} \tag{4.3-5}$$

Since $y_2/y_1 = s_1'/s_1$, therefore,

$$M = s_1'(s_1 + s_1' + s_2) / s_1 s_2 \tag{4.3-6}$$

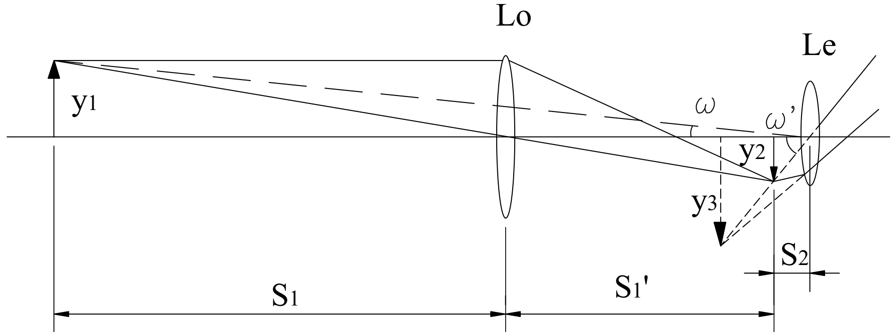

Figure 4.3-4 Schematic of telescope imaging at quasi-infinity.

Experiment Procedures:

1) Refer to Figure 4.3-4, align L_o and L_e in same height on the optical rail with their spacing about f_o+f_e, place the stand ruler in front of L_o at a distance of about 3 meters;
2) Move objective lens *L*o back and forth, behind *L*e, use one eye to observe the image of the ruler till it is clear;
3) Use another eye to directly observe the scale marks on the ruler, count how many scale marks (amount *M'*) on the ruler image directly to the eye are contained in one mark of the magnified image of the telescope; *M'* is the measured magnification of the telescope;
4) Calculate magnification *M* using Eq. (4.3-4), compare it with *M*'.

4.4 Constructing a Slide Projector

Components Required: white light source S, condensing lens L_1 (f'=50 mm), lens holder, transparent slide P, plate holder, projection lens L_2 (f'=190 mm), 2-axis tiltable holder, white screen.

Principle

As shown in Figure 4.4-1, L_1 is a condenser, and L_2 is a projection lens. A slide is just behind L_1 (we can assume $v_1 = u_2$). If the magnification of a slide projector is *M*, the length of slide projector is *D*, and the focal length of L_1 and L_2 are f_1 and f_2, respectively.

By taking $M = v_2 / u_2$, $1/f_2 = 1/u_2 + 1/v_2$, we can get

$$f_2 = \frac{1}{M+1} v_2 \tag{4.4-1}$$

By taking $D = u_1 + v_1$, $v_1 = u_2$, $1/f_1 = 1/u_1 + 1/v_1$, we can get

$$f_1 = \frac{v_2}{M} - \frac{1}{D}\left(\frac{v_2}{M}\right)^2 \tag{4.4-2}$$

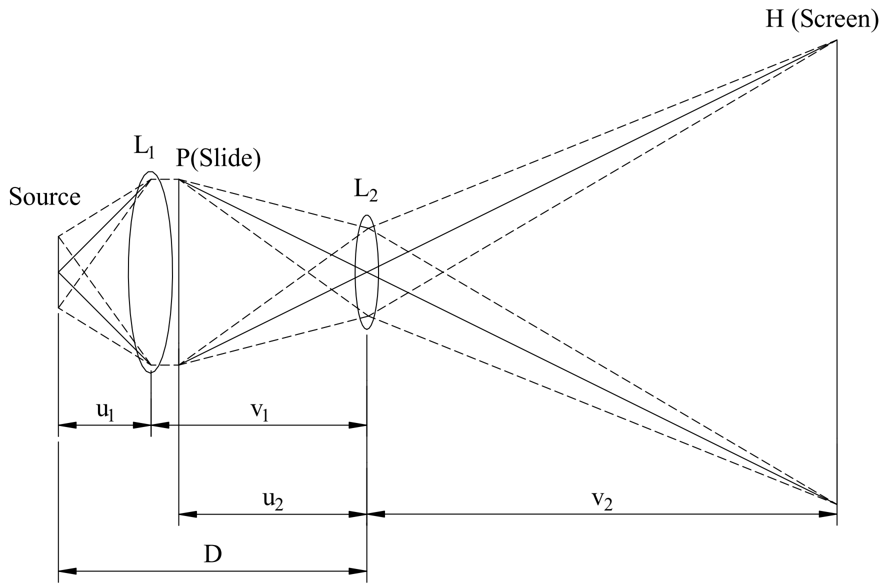

Figure 4.4-1 Schematic of slide projector imaging

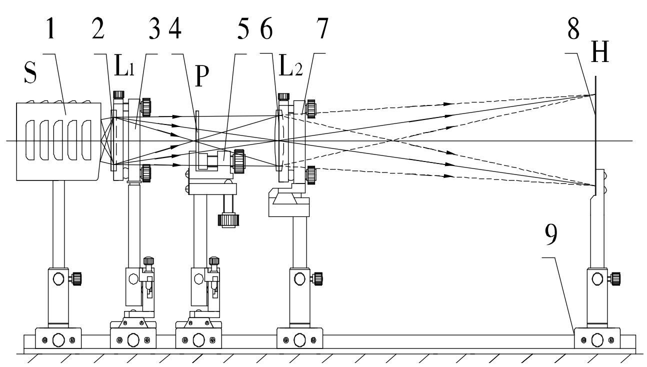

Figure 4.4-2 Configuration of components

1: Bromine Tungsten Lamp S (LLC-3)

2: Condenser Lens L_1 (f_1'=50 mm)

3: Lens Holder (SZ-08)

4: Projector Slide *P*

5: Plate Holder A (SZ-12)

6: Projection Lens L_2 (f_2'=190 mm)

7: 2-axis Tiltable Holder (SZ-07)

8: White Screen (SZ-13)

9: Optical Rail (LEPO-54)

* Ground glass on LLC-3 is not used and Adaptor Piece (SZ-09) can be used

Experimental Procedures:

1) Refer to Figure 4.4-2, align all components in same height on the optical rail, set the distance between L_2 and screen *H* about 0.8 m (if space available, it should be better to set a larger distance);

2) Move slide *P* back and forth, till a clear image (imaged by L_2) is observed on *H*;

3) Fix condenser L_1 as close as possible to *P* (may use the adapter piece SZ-09), remove *P*, move light source *S* back and forth, till the image of *S* formed by L_1 is clear on L_2 aperture plane;

4) Put back slide *P* at its pervious location, observe the brightness and uniformity of the projected image on the screen;

5) Remove L_1, observe the brightness and uniformity of the projected image again, and recognize the function of L_1.

6) Through the experiment, understand the principle of a slide projector and the function of its condenser, learn how to adjust a projection optical system, and understand illuminating condition for achieving a uniform light field on the screen (Kohler illumination).